INEEL/CON-02-00016
PREPRINT

Implications Of The KONVERGENCE Model For Difficult Cleanup Decisions

Steven J. Piet
Patrick L. Gibson
Jeffrey C. Joe
Thomas A. Kerr
Robert L. Nitschke
Maxine E. Dakins

August 4, 2002

Spectrum 2002

Published Spectrum2002 Conference, Reno, Nevada, August 2002

Implications of the *K*ON*VER*GENCE Model for Difficult Cleanup Decisions

Steven J. Piet, Patrick L. Gibson, Jeffrey C. Joe, Thomas A. Kerr, Robert L. Nitschke
Idaho National Engineering and Environmental Laboratory (INEEL)
P.O. Box 1625 Mail Stop 3605
Idaho Falls, ID 83415-3605
pietsj@inel.gov

Maxine E. Dakins
University of Idaho at Idaho Falls
1776 Science Center Drive
Idaho Falls, ID 83402
medakins@if.uidaho.edu

Abstract—*Some cleanup decisions, such as cleanup of intractable contaminated sites or disposal of spent nuclear fuel, have proven difficult to make. Such decisions face high resistance to agreement from stakeholders possibly because they do not trust the decision makers, view the consequences of being wrong as too high, etc. Our project's goal is to improve science-based cleanup decision-making. This includes diagnosing intractable situations, as a step to identifying a path toward sustainable solutions. Companion papers describe the underlying philosophy of the* ***K*ON*VER*GENCE Model for Sustainable Decisions**,[1] *and the overall framework and process steps.*[2] *Where* ***knowledge****,* ***values****, and* ***resources*** *converge (the K, V, and R in* *K*ON*VER*GENCE*), you will find a sustainable decision – a decision that works over time. For intractable cases, serious consideration of the adaptable class of alternatives is warranted – if properly implemented and packaged.*

I. INTRODUCTION

There are many intractable cleanup problems, including complex, contaminated areas at government and private sites. Cleanup issues typically result from past decisions that were considered acceptable at the time by those involved, with the ***knowledge***, ***resources***, and regulations (if any) of the time. (In our model, regulations are an imperfect manifestation of ***values***.[1, 2]) We agree with the quote attributed to A. Einstein, "Problems cannot be solved at the same level of awareness that created them." Our goal is better, participatory science-based decision-making.

The suggestions in this paper were developed during the first half of a 3-year research project. We offer these ideas to solicit feedback and continue progress. You may find it helpful to read the companion papers on framework[2] and then the underlying philosophy[1] before this paper. In the second half of our project, we will further refine and test ideas. This is a research project and does not represent official positions of the Department of Energy or its contractors.

Our approach is based on the need to establish and maintain ***k***on***v***e***r***gence among the three universes of ***knowledge***, ***values*** of those affected by a decision, and available ***resources***. We call this the ***KONVERGENCE* Model for Sustainable Decisions**.[1,2] Investigation and availability of data defines ***knowledge***. Participation of stakeholders specifies ***values***. The availability of budgets, offsite waste disposal sites, etc. drives ***resources***. Acceptable alternatives are those in the *k*on*ver*gence of ***knowledge***, ***values***, and ***resources.*** *K*on*ver*gence must be maintained as the universes change if the decision is to remain acceptable. Some past decisions to bury waste appear to have drifted out of *k*on*ver*gence; such cases have become cleanup challenges. Although we were initially focused on the relatively tractable set of facility decommissioning decisions, our analyses and approach offer constructive suggestions for the most intractable of cleanup problems and even spent fuel disposition. We use the Yucca Mtn case to make several points below because the issues are well known.

Consider these characteristics of intractable cases.

- The hazards will persist for centuries or millennia; humans have little experience in deliberately making decisions with such time horizons, and even less experience in making successful ones.
- Lack of trust is clearly an issue (within the ***values*** universe).
- ***Knowledge*** of how solutions will behave for such time horizons is lacking.
- Provision of ***resources*** for long time frames is needed.

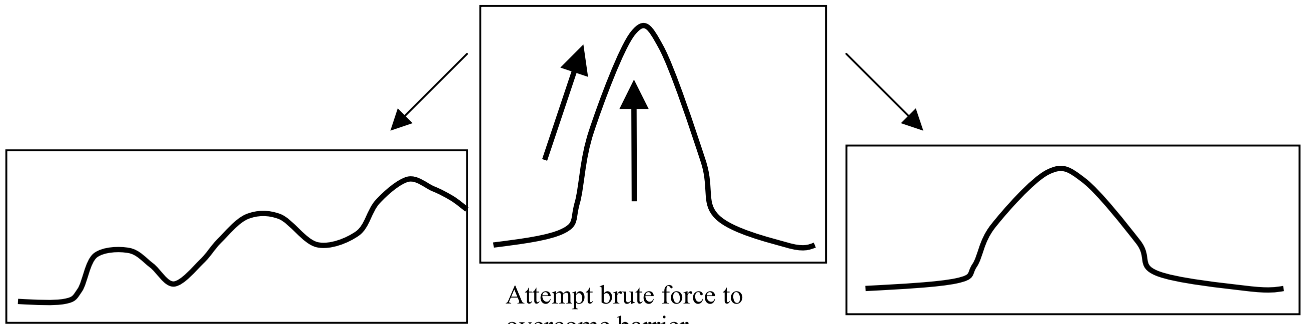

Figure 1. Making decisions easier by reducing the consequences of being wrong or by splitting a single decision into a network of decisions

One cause of difficulty in making long-lasting decisions is the way we approach them. Figure 1 shows a chemical reaction analogy. The typical way we try to make controversial decisions is to attempt brute force to overcome resistance. Yet, in democratic societies, resistance can generally react to such brute force. We then get a force-resistance battle, stalling a decision, while the original problem remains. Perhaps it would be useful to break the single tough reaction (decision) into stages or reduce resistance by reducing the consequences of being wrong (more reversible thermodynamics).

II. CLASSES OF ALTERNATIVES

We characterize alternatives by the variables of hazard (longevity, severity, etc.) and adaptability of solutions (figure 2). "Adaptability" encompasses reversibility (implies going back to the starting point), repairability, fixability (implies only patching the current approach), and flexibility.

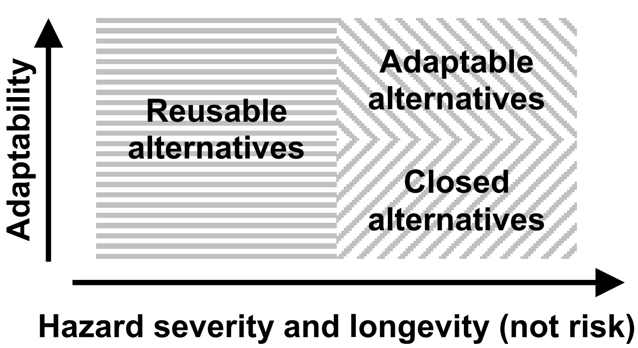

Figure 2. Hazard-Adaptability Space

Three hazard-adaptability regions or classes are:

- **Reusable** - Relatively low hazard, variable adaptability - Facility can be released for other purposes, by other groups – with or without restrictions on use. If any use of the facility/land would lead to acceptable risk, the release is "unrestricted", e.g., greenfield. If some uses would pose unacceptable risks, the release is "restricted", e.g., brownfield sites.
- **Closed** - Relatively high hazard, relatively low adaptability - Facility is put into a state with little adaptability, with little or no intention to revisit later. Examples include so-called "entombed" facilities or deep waste disposal sites after the facility is sealed.
- **Adaptable** - Relatively high hazard, relatively high adaptability - Facility is kept in an adaptable state, thereby keeping future options open while keeping the risk from hazards acceptable to stakeholders. Examples include the concept of "assured storage" or "assured isolation" of low-level radioactive waste,[3, 4] the Hanford C reactor, temporary spent fuel storage at commercial power plants, and the National Research Council's suggestion for adaptive staged decisions at Yucca Mtn.[5, 6]

III. REUSABLE ALTERNATIVES

There is no alternative class that works best for all cleanup problems. Consider the **reusable** class of alternatives. If we know how to cleanup a site (***knowledge***) and have the ***resources*** to do so (budget and place to send resulting waste) this solution is usually implemented because such cleanup is generally consistent with ***values***. The pace of cleanup is typically controlled by budgets, which result from ***value***-based prioritization of various needs. (***Values*** manifest themselves imperfectly in political decisions and in the rules and regulations of the moment.[1])

Consider cases where one of the above conditions is not met. For example, reusable alternatives may be within the ***values*** universe but not within ***knowledge*** (lack of confidence in the technology to remove or destroy the hazards) or ***resources*** (no offsite waste disposal, inadequate budget). Consider spent nuclear fuel as an example – there is no current method to destroy the hazard and no place to permanently place it. Other examples are heavily contaminated sites for which no technology exists that allows cleanup at acceptable levels of risk and cost (***knowledge*** and/or ***resource*** problems).

Then, figure 3 shows how critics might view reusable alternatives. The universes of ***knowledge***, ***resources***, and ***values*** are each represented by a circle. The black circle shows that under these circumstances reusable alternatives would be consistent with ***values*** but possibly not with ***knowledge*** and ***resources***, it lies at or outside of the ***knowledge*** and ***resource*** circles. Advocates may view things differently. Our hypothesis is that an alternative will not be acceptable over time if it is not in the *K*ON*V*E*R*GENCE area of the diagram, i.e. consistent with all three universes.

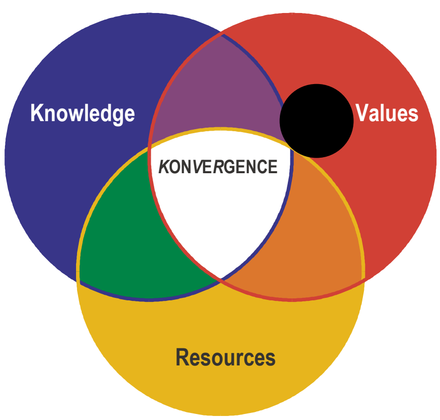

Figure 3. Reusable alternatives with *knowledge* and *resource* concerns

IV. CLOSED ALTERNATIVES

Next consider **closed** alternatives. Grouting is one common technology. It is generally known how to fill a facility or waste site with grout, yet long-term barrier behavior may not be adequately understood. Offsite waste disposal is not needed, removing one ***resource*** constraint. (But it does require a new ***resource*** constraint, long-term land use.) Budget is typically available. Such alternatives are generally consistent with ***resources*** and partially consistent with ***knowledge***.

What about ***values***? We posit a generic hierarchy of 4 values (equality, democracy, truth, reason) and 20 principles, to be rechecked for any specific problem.[2] If the hazards are recognized as relatively low and short-lived, a **closed** alternative is often acceptable. However, if "permanent" closure is viewed as posing substantial risk to future generations, it can run afoul of several principles under the **equality** value (decisions are just for current and future generations):

- **Trustee Principle** – "Every generation has obligations as trustee to protect the interests of future generations."[7]
- **Sustainability Principle** – "No generation should deprive future generations of the opportunity for a quality of life comparable to its own."[7]
- **Precautionary Principle 1** – "Actions that pose a realistic threat of irreversible harm or catastrophic consequences should not be pursued unless there is some compelling countervailing need to benefit either current or future generations."[7]

Complying with regulations may be inadequate to convince opponents that permanent closure decisions are consistent with their ***values***. Examples include closure of sites with significant levels of long-lived hazards and "permanent" storage of spent nuclear fuel. The U.S. has existed for less time than such hazards will last; people intuitively doubt whether regulations and associated implementing authorities offer adequate protection for centuries. Our first 42 presidents had average terms of about 5 years. Thus, a waste disposal site to operate for 1,000 years spans about 200 U.S. presidential administrations. Research indicates that it is not just an issue of trust; survey participants recognized that there are limits to ***knowledge*** for such time horizons.[8]

One difficulty is inconsistency in time horizon among regulations, which inhibits having a clear dialogue and societal approach to long-term hazards, especially for contaminated sites involving multiple types of hazards. Consider the following range of regulatory time horizons.

- 10,000 years - Nuclear Regulatory Commission and EPA regulations for high-level and transuranic waste (10CFR60, 10CFR63, 40CFR191, 40CFR197).
- 1,000 years – EPA regulations for near-surface uranium and thorium mill tailings (40CFR192) and DOE policy for new land burial (DOE M 435.1).
- 500 years – NRC regulations for near-surface burial of low-level waste (10CFR61).
- 30 years – baseline EPA RCRA time period for near-surface burial chemical hazards (40CFR264); EPA can increase or decrease this value for each case.
- Indefinite – baseline EPA CERCLA time period for residual hazards. CERCLA requires a 5-year review

to ensure the remedy is still protective of human health and the environment and is still performing as predicted. We are not aware of a CERCLA remedy designed to operate for millennia.

These differences are not directly related to the longevity of the hazards, as pointed out by Okrent[9] and Kadak.[10] For example, toxic metals do not decay significantly, yet they are regulated for orders of magnitude less time than radiological hazards, which do decay significantly. This situation can create conflict between short-time-horizon regulations and intergenerational ***values***.

When critics view closed alternatives as having adequate ***resources***, but also having gaps in ***knowledge*** of long-term behavior and inadequate attention to intergenerational ***values,*** they are viewing closed alternatives as shown in figure 4. Advocates may view things differently. Indeed, advocates can be correct in saying that a closed alternative is consistent with a short-term regulation (e.g. 30 years). The underlying problem is that regulations and ***values*** are not always in harmony; our model considers regulations as an imperfect overlay of **values**; eventually the differences should decrease.[1] If so, a solution consistent with regulations today may become divergent with ***values*** and regulations later.

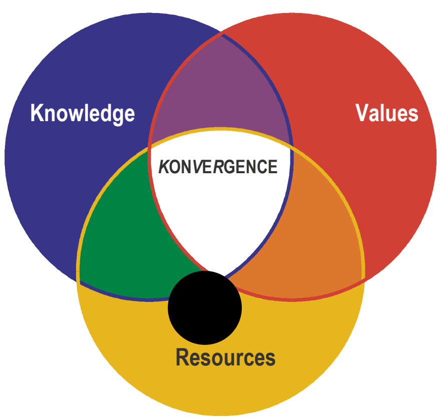

Figure 4. Closed alternatives with *values* and *knowledge* concerns

There are many non-DOE sites already closed with residual hazards in place where the long-term solution may not perform adequately for the duration of the hazards. If so, those solutions may drift out of *k*on*ver*gence and new cleanup challenges will arise.

V. NO ACTION IS DANGEROUS, WRONG ACTION IS DANGEROUS

In such situations, figures 3 and 4 show that neither reusable nor closed alternatives are in *k*on*ver*gence. A polarized situation has developed. Even if such a reusable or closed alternative is selected, the longevity of the decision is suspect.

Those favoring the reusable and closed classes of alternatives may not talk the same language. Those supporting closed alternatives may believe the problem is only that opponents are not listening to their ***knowledge***. Those opposed may understand the technical arguments but be unconvinced about the certainty of protection over the duration of hazards. This pattern appears for many closed alternative cases including buried waste and spent fuel disposition.

Those supporting reusable alternatives may believe that others simply do not share their ***values***; yet people can share such ***values*** but realize that the reusable alternatives run afoul of technical and budget limitations. Again, the same pattern appears in many cases.

In such polarized situations, parties often seek advantage through legal-regulatory procedures.

In such cases, neither reusable nor closed alternatives can be implemented. Or, if they are implemented, they are unlikely to be sustained unless the ***knowledge***, ***values***, and ***resource*** universe change so that the decision comes into *k*on*ver*gence later.

Until a reusable or closed alternative comes into *k*on*ver*gence, something must be done with the hazards. If the hazard is not stable or its protective barriers are degrading or already inadequate, the worst action is "no action". For *siting* decisions, the "no action" alternative is often safe. But, in *unsiting* decisions, when the hazards already exist, legal-regulatory stalemate causing "no action" can be dangerous. It runs afoul of **Precautionary Principle 2** – "Where there are threats of serious or irreversible damage, scientific uncertainty shall not be used to postpone cost-effective measures to prevent environmental degradation."[11]

VI. WHAT CAN BE DONE?

We suggest combining step-wise adaptable solutions with sincere, diligent efforts to increase the likelihood that reusable and/or closed alternatives may enter *k*on*ver*gence in the future. Plans to increase the range of future options are needed to prevent those advocating reusable or closed alternatives viewing step-wise approaches as a sham. Said another way, if there is no plan B, then everyone recognizes that all efforts are devoted to forcing plan A to work. This means we need a package:

- Proceed in a step-wise decision network fashion. Put the hazards/facility into a configuration where they are safe, at least temporarily, maintaining maximum adaptability.
- Research better ways to cleanup (or at least reduce) the hazard, to possibly bring reusable alternatives

into *k*on*ver*gence. For existing intractable waste sites, this includes research into decommissioning and cleanup technologies. For spent nuclear fuel, the volume of long-term waste can conceivably be reduced orders of magnitude by separating long-lived isotopes and separately storing short-lived isotopes. The long-term hazard could be conceivably reduced, subject to ***values*** issues, by reusing useful long-lived isotopes (reprocessing) or burning them in reactors. Accelerator transmutation of waste (ATW) may also be helpful if technical and cost issues can be overcome.

- Improve understanding of multi-generational risks, to possibly bring closed alternatives into *k*on*ver*gence. Improve monitoring of hazards that have already been put into closed or closed-like configurations. For example, if spent fuel were loaded into Yucca Mtn, study how the system performs for hundreds of years before further reducing adaptability. Where waste is left in existing intractable waste sites, conduct the research needed to substantially improve understanding of long-term risk.

All parts are needed. If, for example, efforts that might bring reusable alternatives into *k*on*ver*gence in the future is left out, then people will conclude that the only long-term solution will be a closed one and that delay is only that – there is inadequate possibility of a different "end state," only a slower path in getting there.

VII. DYNAMIC NOT STATIC ANALYSES

Long-duration problems require dynamic analysis, examining how things may change. The solution and/or the three universes of ***knowledge***, ***values***, and ***resources*** may change. The three universes themselves interact.

For example, sustained changes in ***values*** leads to changes in available ***resources***. The response time varies according to the ***resource*** in question. Opening a new waste disposal site (a ***resource*** for an existing contaminated site) takes time. Sustained allocation of ***resources*** to research can increase ***knowledge***. Increased ***knowledge*** can change ***values*** or the relative weights among ***values***. The events of 9/11/2001 and the realization of the threat of terrorism changed ***values***. Sustained changes in ***values*** also lead to changes in rules and regulations.

VIII. CHARACTERISTICS NEEDED FOR ADAPTABLE NETWORKED ALTERNATIVES

To be effective, adaptable, networked alternatives must have certain characteristics, including the following:

(1) Minimize the chance of getting stalled at an intermediate point out of *k*on*ver*gence. Start by defining the network of related points. We characterize relationships as either **staged** or **linked**.

An adaptable approach implies a network of **staged** decisions - a path of related decisions that must be completed before going to the next one. Each staged decision must be in *k*on*ver*gence before taken. The network can be very simple – a decision today to establish an adaptable configuration leading to a second decision some years later (or triggered by some event) at which time a selection between reusable or closed alternatives would be made. This is envisioned for the C reactor at Hanford. Or, the network may be quite complex. (Other situations also create decision networks, such as when a key assumption cannot be validated nor R&D results obtained until later.)

We define **links** as series of smaller, shorter-term actions or decisions that are taken to implement staged decisions. Individual links may not be in *k*on*ver*gence, it is not important that they be so since they are shorter-term. Stakeholders will tolerate a set of linked steps to get to the next staged decision that is in *k*on*ver*gence. If there is a reasonable chance of being stopped at an intermediate link along the path, then it is important to think about contingencies that would be in *k*on*ver*gence. One does not start a set of linked decisions unless it can be finished within the window of stakeholders' tolerance.

Consider the steps in moving spent fuel from its current location to Yucca Mountain (above ground), then into the mountain, then someday sealing (closing) the disposal facility. To the extent possible, we should minimize the chance of shipments getting stalled at the above ground receiving station. Even worse would be shipments stalled in transit to Yucca Mountain.

(2) For intermediate points with a significant chance of being divergent, consider what might be necessary to move to a point in *k*on*ver*gence. This is part of the definition of what it takes to be adaptable. Adaptability assessments should include the financial cost needed to move from the possibly divergent point to one that may be in *k*on*ver*gence. This is not a "sunk cost" assessment unless the best path toward *k*on*ver*gence is back along the path to the starting point (merely reversing the action). For grouted waste in place, the adaptability cost could include the cost of cutting and removing the grouted waste. Or, it may be the cost to add additional barriers if the initial barriers have failed. This should be tempered with an assessment of the probability of finding that an intermediate point is divergent.

An analogy may be helpful. Consider a decision as a mass connected to the *k*on*ver*gence area by a spring. As the mass becomes further out of *k*onvergence because the universes move, the force trying to pull the mass back to *k*on*ver*gence increases. The mass (inertia) represents the adaptability of the implemented decision; the friction coefficient represents decision processes. If restoration of *k*on*ver*gence is resisted too long, then when change eventually happens, there can be an overcorrection. The decision mass can overshoot the *k*on*ver*gence zone.

Consider long-lived buried waste. The decision to put it there was in *k*on*ver*gence with the ***values*** of those involved with the decision at the time. In some cases, that decision is now divergent. Where it is relatively easy (low adaptability pain, responsive decision processes) to adjust that decision, such adjustments are typically done. Where adjustments are not so easy, e.g. costing billions of dollars and requiring offsite waste disposal options that do not yet exist (two ***resource*** constraints), adjustments are understandably resisted because the "obvious" alternative (full retrieval) is itself not in *k*on*ver*gence. Yet, the current decision (black circle in figure 5) is drifting further out of *k*on*ver*gence, with force building toward full retrieval (gray circle).

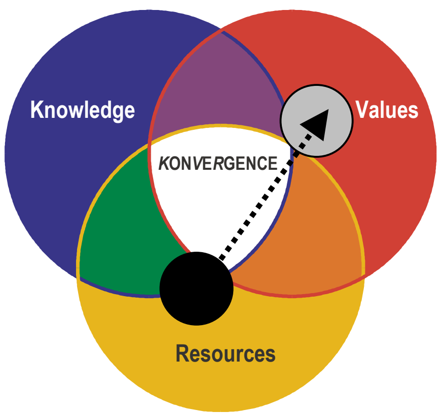

Figure 5. Pressure builds to move a divergent point back to *k*on*ver*gence or beyond

(3) Assess how risk, cost, and other key parameters vary with time. If hazards are to be left for significant time, there will be some barriers to further prevent or mitigate any spread of contamination. Consider risk as the hazard divided by barrier effectiveness. We know how radioactive hazards change with time; time dependence of chemical hazards may be uncertain. The barrier degradation may also be poorly known over the lifetime of the hazards in question.

It is relatively safe to wait (Table I) if the existing barrier is slowly degrading while the hazards are quickly decaying; it is also often advantageous because letting the hazard decay in place probably reduces worker risk to treat or remove it and public risk to move it.

Sometimes people cannot agree on the absolute risk posed by an existing hazardous site. In such cases it may still be possible to agree on what conditions and actions lead to relative risk reduction. Risk is always decreasing if the absolute value of $\Delta H/H > \Delta B/B$ and exposure scenarios remain constant.

Table I. Relative urgency to take action

		Hazard decay rate	
		Low	High
Existing barrier decay rate	High	Dangerous to wait	
	Low		Relatively safe to wait

(4) Consider adaptability as one of the desirable attributes to optimize, along with cost, risk, and others. In generating a network of possible stages, leading ultimately to reusable or closed alternatives (perhaps very far into the future), consider dynamic tradeoffs among risk, cost, adaptability, etc.

For example, Newberry, Kerr, and Leroy have published a series of articles on the "assured isolation" of low-level radioactive waste (originally called assured storage).[3,4] Assured isolation is defined as "an integrated management system for safely isolating waste, while preserving options for its long-term management, through: robust, accessible facilities; planned preventive maintenance; and sureties adequate to address contingencies or implement future alternatives."[3] An assured isolation facility is specifically intended to be adaptable as contemplated by our definition "…the waste would remain in a retrievable condition that would not foreclose options for future generations to remove the waste for recycling, repackaging, treatment, or disposal as new technologies become available."[4] The assured isolation concept also specifically acknowledges, however, that "if a facility succeeds in safely isolating the waste over centuries, the site operator and regulator of that future time might evaluate the facility's performance and decide to curtail or discontinue active institutional controls. Some or all of the waste units may finally be backfilled and closed. Our descendants will have professional judgment at least equal to ours, actual empirical data with which to evaluate future performance, and much better predictive techniques."[4]

For another example, Flüeler[12] has ordered various Yucca Mountain suggestions:

- "Nuclear Guardianship" (above ground)
- "Monitored retrievable storage" (above ground)
- "Underground retrievable storage"
- "Underground retrievable disposal"
- "Extended" final disposal or "monitored long-term geological disposal"
- "Final disposal"

from high to low "control intervention." This is similar to our adaptability dimension in so far as higher "control intervention" means increased ability to adapt (control) the current situation to fix a problem. He notes that the ordering of these suggestions reverses for passive protection. This spectrum of suggestions would similarly align along the right edge of our figure 2. He finds "monitored long-term geological disposal" as particularly robust. "In general, a system is robust if it is not sensitive to significant parameter changes; and most arguments, evidence, social alignments, interests, and cultural values lead to a consistent option."[12] This idea is to emplace the waste, establish co-located research facilities, and maintain waste retrievability if research does not tend to validate predictive performance models. We describe this as having only modest adaptability because the large costs of emplacing wastes would have already been incurred and it lacks a provision for plan B, if plan A diverges.

Consider figure 6. The upper line represents a path of stages that initially lose relatively little adaptability concurrent with major risk reduction. The lower path loses significant adaptability first, with most risk reduction occurring later. The upper path is often preferable; other matters such as time scale and the absolute value of risk are important. For example, it may be preferable to reduce risk quickly (even with loss of adaptability) if the risk is significant and would otherwise persist for centuries. The point is to examine how various characteristics (including adaptability) vary as the network unfolds.

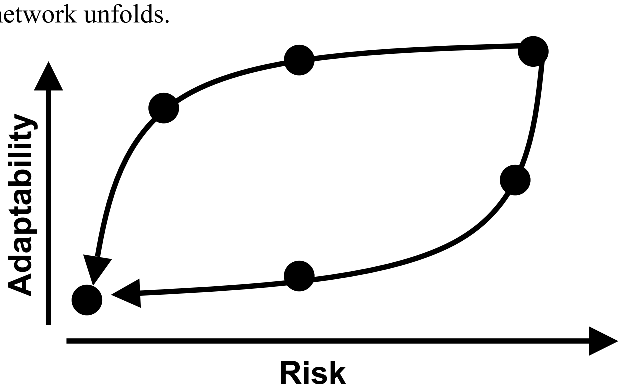

Figure 6. Possible Adaptability-Risk Paths

One can create similar diagrams for other variables, including financial cost/risk and cost/adaptability

(5) Explicitly discuss the risk of being divergent at intermediate points, the level of adaptability, and tradeoffs among adaptability, risk, cost, etc. with those affected by the decision. The more transparent, open, complete, the discussion is, the better.

Decisions cannot be made and sustained without agreement with ***values***. One element of ***values*** is trust. Jenkins-Smith and Kunreuther[13] have studied the level of support for siting a prison, landfill, hazardous waste incinerator, or high-level nuclear waste repository as a function of trust, perceived risk, and various benefits (both financial and safety, such as increased local control, oversight, etc.) Table II summarizes some of their results.

Table II. Interaction among trusts and perceived risk in predicting support for an action[13]

		Risk	
		Low	**High**
Trust	**High**	Hard-core supporters	Movable
	Low	Movable	Hard-core opponents

The concepts of "perceived value and/or threat" and "personal inconvenience costs" suggest when and how strongly people may become involved.[14] Involvement is more likely and stronger as the "perceived value and/or threat" is higher and the "personal inconvenience costs" of involvement is lower. Harbour et al focus on what induces people to join "activist" campaigns against a possible environmental threat:[14]

- Convince people that the environmental threat is high and/or the value of their involvement in stopping the threat is high.
- Make it easy and painless to become involved.

Our objective is different but the concepts are the same. To increase involvement in the decision rather than a campaign to stop a decision later (late-entry players):

- Increase the value of their involvement by engaging them early enough and openly enough that their concerns enter the decision process. Show that their involvement matters. Our generic set of ***values*** and principles[2] addresses these objectives.
- Make it easy to become involved.

IX. CONCLUSIONS

We doubt that existing decision analysis approaches will be adequate to resolve and sustain intractable cleanup and waste management decisions – those with very long time scales. Many current difficulties stem from past decisions, which often looked acceptable at the time – at least to those involved. New approaches are needed, such as the ***K*ON*V*E*R*GENCE Model for Sustainable Decisions**.[1,2] Only two strategies are potentially sustainable. One, use solutions that are adaptable as ***knowledge***, ***values***, and ***resources*** change. Two, manage the three universes to maximize the chance that a low-adaptable solution remains in *k*on*ver*gence.

When neither reusable nor closed alternatives appear likely to be and to remain in *k*on*ver*gence over the time periods associated with a decision, consider adaptable alternatives. Where maximum adaptability is appropriate, a package approach is needed:

- Progress in a step-wise adaptable fashion. Put the hazards/facility into a configuration where they are safe, at least temporarily, maintaining as much adaptability as possible.
- Research better ways to cleanup (or at least reduce) the hazard, to possibly bring **reusable** alternatives into *k*on*ver*gence.
- Improve understanding of multi-generational risks, to possibly bring **closed** alternatives into *k*on*ver*gence.

We offer these further suggestions:

(1) Minimize the chance of getting stuck at an intermediate point out of *k*on*ver*gence.
(2) For intermediate points with a significant chance of being divergent, consider what might be necessary to move to a point in *k*on*ver*gence.
(3) Assess how risk, cost, and other key parameters vary with time.
(4) Consider adaptability as one of the desirable attributes to optimize, with cost, risk, etc.
(5) Explicitly discuss the risk of being divergent at intermediate points, the level of adaptability, and tradeoffs among adaptability, risk, cost, etc. with those affected by the decision.

Other suggestions regarding Yucca Mtn are broadly consistent with others' suggestions[5, 6, 12] and how we observe the debate evolving (more emphasis on learning from reversible waste emplacement, funding of ATW, reprocessing being considered, etc.). We suggest putting more emphasis on having a network of staged decision points (maximizing adaptability) with multiple "end states", rather than a single path toward a pre-defined end-state, and on the need to plan to sustain *k*on*ver*gence.

Similar adaptable networked approaches can and should be developed for high-hazard, long-duration, intractable cleanup sites.

We recognize the potential ongoing cost and risk associated with adaptable solutions but this has to be weighed against the cost and risks of a "no action" stalemate, of premature reusable alternatives (if attempted with inadequate ***knowledge***), and of premature closed alternatives (if we really do not know that long-term behavior will be acceptable).

X. ACKNOWLEDGEMENTS

This work is supported through the INEEL's Laboratory-Directed Research and Development (LDRD) Program under DOE Idaho Operations Office Contract DE-AC07-99ID13727. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

XI. REFERENCES

1. KERR, T. A. et al, *The K*ON*VER*GENCE *Model for Sustainable Decisions, Spectrum2002*, Reno, Nevada (2002).
2. PIET, S. J. et al, *A Framework for Making Sustainable Cleanup Decisions Using the K*ON*VER*GENCE *Model, Spectrum2002*, Reno, Nevada (2002).
3. KERR, T. A. and NEWBERRY, W. F., *The Assured Storage Integrated Management System: What is it and what will it cost?,* EPRI International Low-Level Radioactive Waste Conference, New Orleans, LA (1996).
4. NEWBERRY, W. F., KERR, T. A., LEROY D. H., "Assured Storage Integrated Management Systems: The Most Frequently Asked Questions," *Radwaste*, **3**, *5*, pages 20-25 (1996)
5. BOARD ON RADIOACTIVE WASTE MANAGEMENT, *Principles and Operational Strategies for Staged Repository Systems: Progress Report*, National Research Council (2002).
6. NATIONAL RESEARCH COUNCIL, *Disposition of High-Level Waste and Spent Nuclear Fuel – the Continuing Societal and Technical Challenges*, National Academy Press, Washington DC (2001).
7. *Deciding for the Future: Balancing Risks, Costs, and Benefits Fairly Across Generations*, A Report by the Panel of the National Academy of Public Administration for the Department of Energy (1997).
8. SJÖBERG, L., "Limits of Knowledge and the Limited Importance of Trust," *Risk Analysis*, **21**, *1*, pages 189-198 (2001).
9. OKRENT, D., "On Intergenerational Equity and Its Clash with Intragenerational Equity and on the Need for Policies to Guide the Regulation of Disposal of Wastes and Other Activities Posing Very Long-Term Risks," *Risk Analysis*, **19**, *5*, pages 877-901 (1999).
10. KADAK, A. C., "Intergenerational Risk Decision Making: A Practical Example," *Risk Analysis*, **20**, *6*, pages 883-894 (2000).
11. *Rio Declaration on Environment and Development. United Nations Conference on Environment and Development*, *Earth Summit*, Rio de Janeiro, Brazil, UN Publication No. E.73.II.A.14 (1992).
12. FLÜELER, T., "Options in Radioactive Waste Management Revised: A Proposed Framework for Robust Decision Making," *Risk Analysis*, **21**, *4*, pages 787-799 (2001).
13. JENKINS-SMITH, H. and KUNREUTHER, H., "Mitigation and Benefits Measures as Policy Tools for Siting Potentially Hazardous Facilities: Determinants of Effectiveness and Appropriateness," *Risk Analysis*, **21**, *2*, pages 371-382 (2001).
14. HARBOUR, J. L., BLACKMAN, H. S., NADEAU, J. L., "Environmental Decision Making: A System-Based Perspective," submitted to *Environmental Management*.